Fire Safety Engineering using DIANA FEA

Source: http://www.mace.manchester.ac.uk/project/research/structures/strucfire/CaseStudy/HistoricFires/BuildingFires/default.htm

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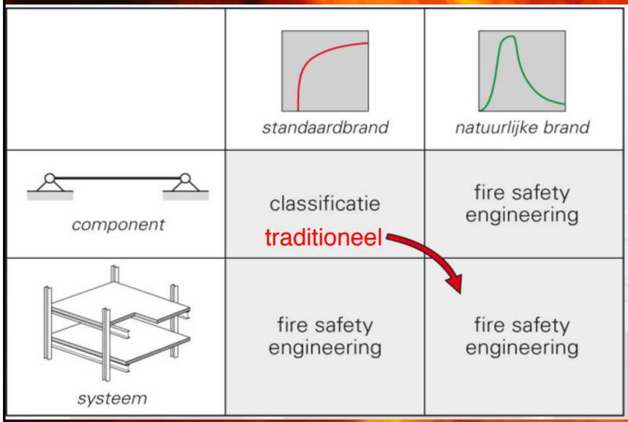
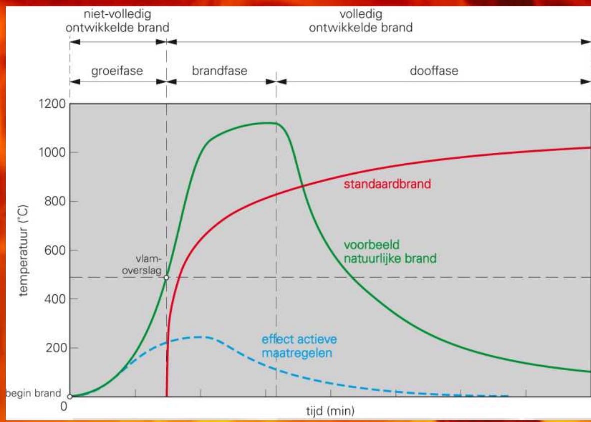
- Summary & Conclusions

Source: seminar Fire Safety Engineering, Bouwen met Staal, 1 November 2018, Ralph Hamerlinck

Introduction - What is Fire Safety Engineering?





Source: seminar “Fire Safety Engineering met staal in Nederland”, Bouwen met Staal, 1 November 2018, Ralph Hamerlinck

Introduction - Why Fire Safety Engineering?

- Better understanding of “real” fire load on a structure
- Better understanding of the mechanical behaviour of a structure in a fire
- Save structural material and or protective cladding / paint

- Annex E “Fire load densities” of NEN 1991-1-2 will be normative in Dutch NA 2018

Software for Fire Safety Engineering

Fire:

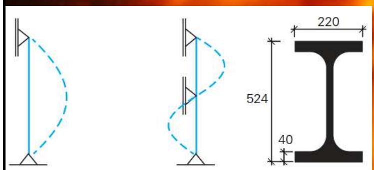
- OZone https://www.brandveiligmetstaal.nl https://sections.arcelormittal.com/design_aid/design_software/EN
- FDS https://pages.nist.gov/fds-smv/
- General purpose CFD softwares

Structure:

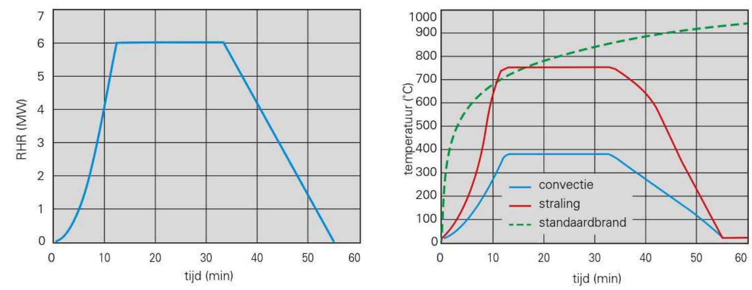
- General purpose FEA softwares with options for thermo-mechanical analysis (DIANA FEA, ABAQUS, ANSYS, …)
- Excel tools for comparison / verification https://www.brandveiligmetstaal.nl

Case I - Buckling of a steel façade column exposed to fire
Starting points

- Meeting room with a vide – ceiling height 10 m
- Localized fire according to NEN-EN 1991-1-2 / NEN 6055
- Steel column S355
- N_{Ed} = 2750 kN
- $M_{Ed;y}$ = 180 kNm
- $M_{Ed;z}$ = 0 kNm

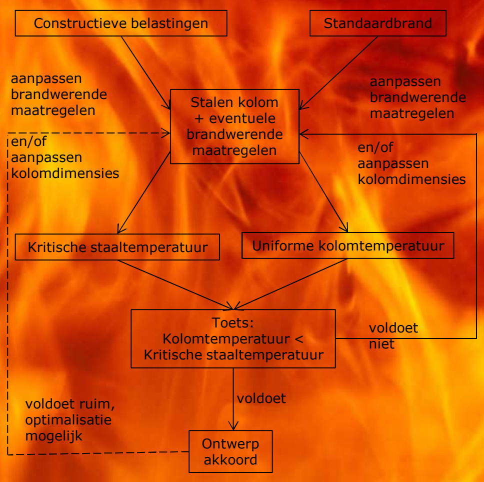


1. Links: schematisatie kolom, kniklengte sterke as 10 m. Midden: schematisatie kolom, kniklengte zwakke as 5 m. Rechts: kolomdoorsnede.

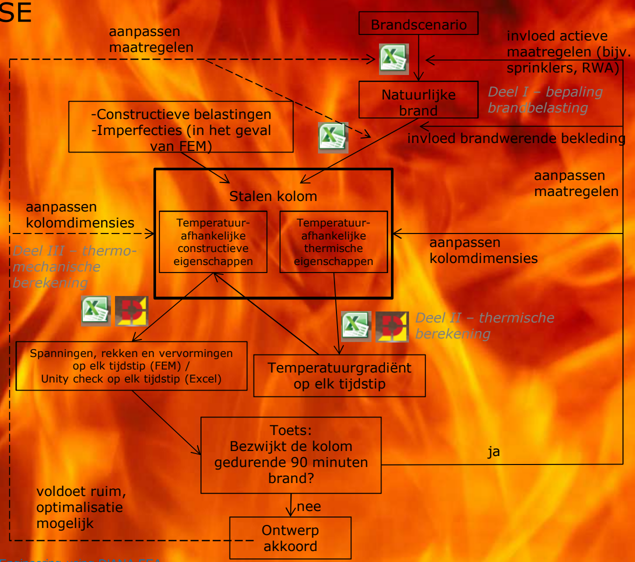


4. Links: vermogen van de brandende vergaderzaal. Rechts: stralings- en convectietemperatuur bij de gevelkolom door de brandende vergaderzaal (let op: stralings- en convectietemperatuur zijn niet gelijk aan de staaltemperatuur). Ter referentie is ook de standaardbrandkromme weergegeven.

Case I - Buckling of a steel façade column exposed to fire
Common approach without FSE

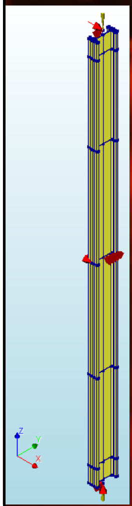


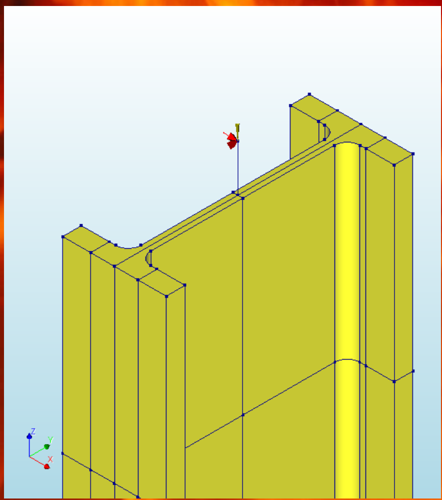
Case I - Buckling of a steel façade column exposed to fire
Approach with FSE

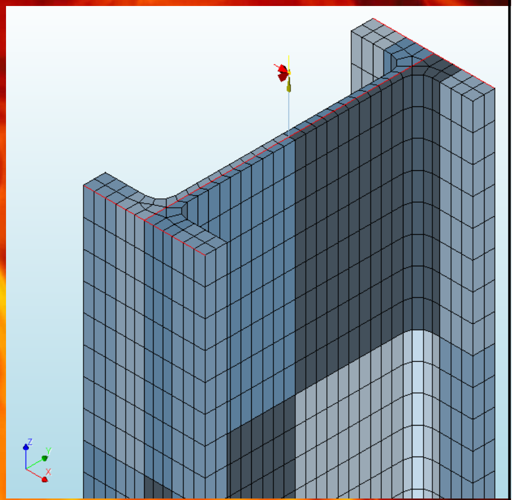


Case I - Buckling of a steel façade column exposed to fire

DIANA model geometry and mesh

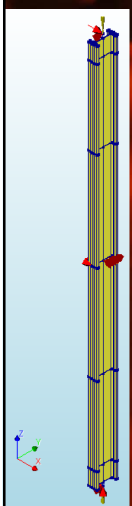


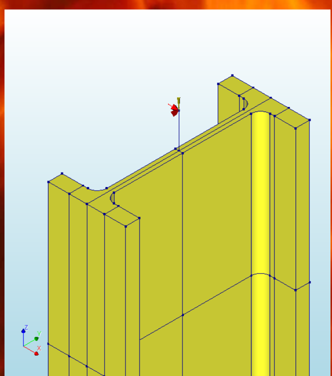


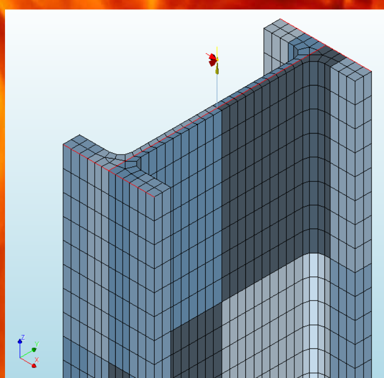


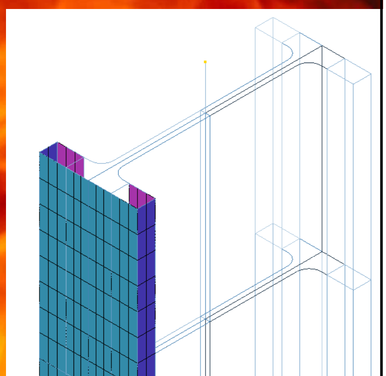
Case I - Buckling of a steel façade column exposed to fire

DIANA model geometry and mesh









Case I - Buckling of a steel façade column exposed to fire

DIANA model material properties

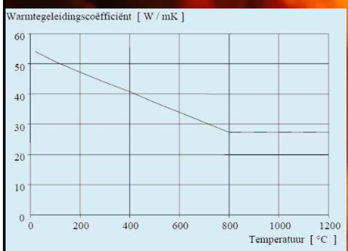
- NEN-EN 1993-1-2 provides all the input
- SI units!
- Temperature-dependent thermal properties of steel (conductivity / capacity)
- Temperature-dependent mechanical properties of steel (Young's modulus / thermal expansion / yield stress)
- Heat transfer coefficients of boundary elements (conduction coefficient / emission coefficient)

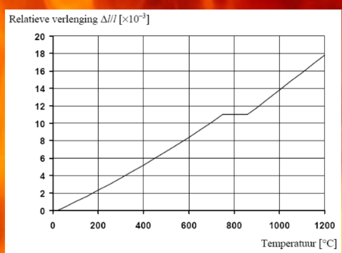
- NOTE: NEN-EN 1993-1-2 provides specific heat capacity; DIANA requires volumetric heat capacity
  volumetric heat capacity [J/(m^{3}K)] = specific heat capacity [J/(kgK)] * density [kg/m^3]

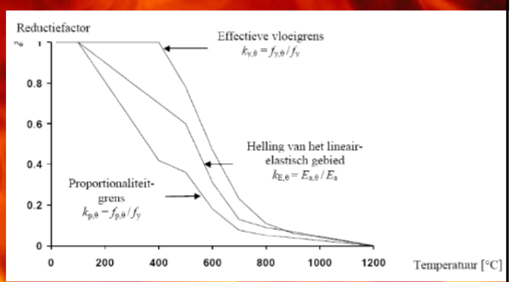
- NOTE: NEN-EN 1993-1-2 provides relative thermal elongation with respect to room temperature;
  DIANA requires thermal expansion coefficient = first derivative of the relative elongation

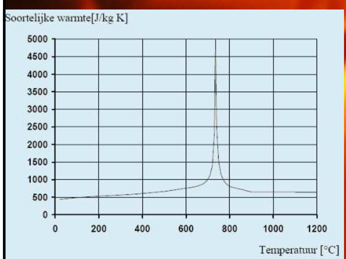
Case I - Buckling of a steel façade column exposed to fire

DIANA model material properties





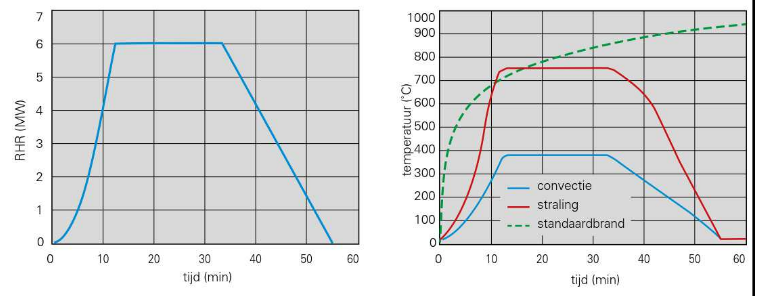




Case I - Buckling of a steel façade column exposed to fire

DIANA model loads

- Mechanical loads as usual
- Thermal loads
  - o Initial temperature field
  - o Convection temperature-time curve
  - o Radiation temperature-time curve
- Order of loads
  - o Mechanical then thermal
  - o Thermal then mechanical

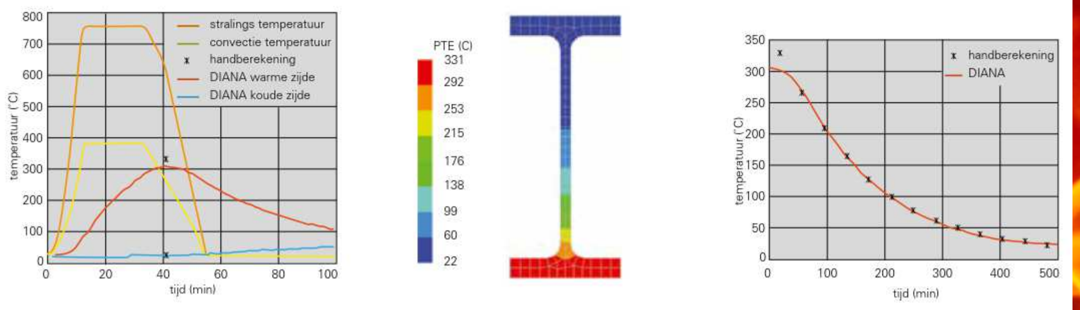


4. Links: vermogen van de brandende vergaderzaal. Rechts: stralings- en convectietemperatuur bij de gevelkolom door de brandende vergaderzaal (let op: stralings- en convectietemperatuur zijn niet gelijk aan de staaltemperatuur). Ter referentie is ook de standaardbrandkromme weergegeven.

Case I - Buckling of a steel façade column exposed to fire

DIANA model thermal results

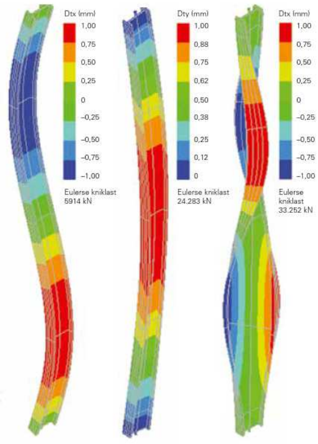
- Good match DIANA vs Excel calculation



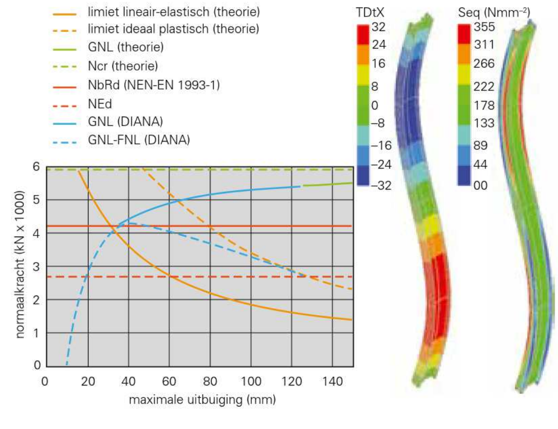
6. Links: temperatuurbelasting en kolomdoorsnede vs tijd. Midden: temperatuurgradiënt DIANA na 40 minuten brand. Rechts: temperatuurgradiënt DIANA vs. Excel-berekening.

Case I - Buckling of a steel façade column exposed to fire

DIANA model validation at room temperature



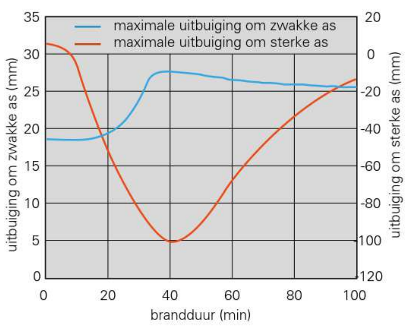
9. Links: knik om de zwakke as. Midden: knik om de sterke as. Rechts: torsieknik.

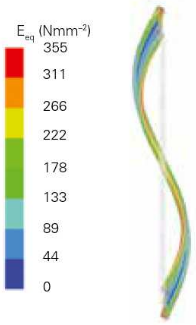


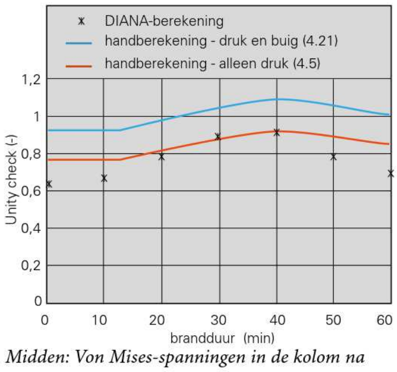
8. Links: normaalkracht vs. uitbuiging. Midden: uitbuiging bij maximale normaalkracht. Rechts: Von Mises-spanning bij maximale normaalkracht.

Case I - Buckling of a steel façade column exposed to fire

DIANA model thermo-mechanical results



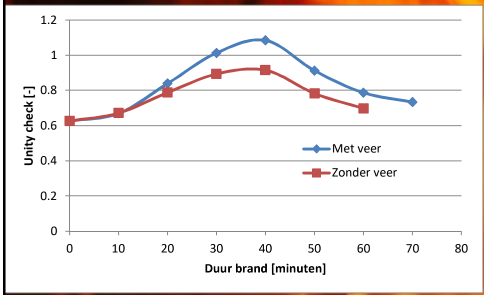


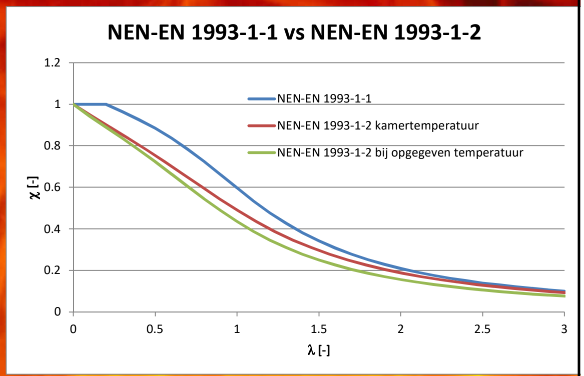


7. Links: maximale uitbuiging om de zwakke en sterke as gedurende de brand (bij gelijkblijvende normaalkracht). Midden: Von Mises-spanningen in de kolom na 40 minuten brand. Rechts: unity check gedurende de brand volgens DIANA-berekening vs. Excel-berekening.

Case I - Buckling of a steel façade column exposed to fire

DIANA model thermo-mechanical results





Case I - Buckling of a steel façade column exposed to fire

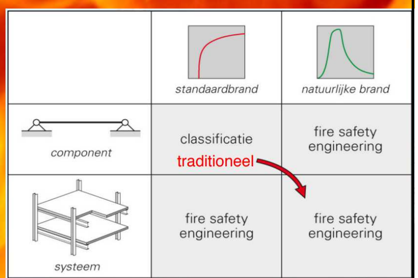
Conclusions

- Standard approach is overly conservative in this case
- DIANA gives additional information about sensitivity to imperfections and about residual deformations
- Excellent agreement between Excel and DIANA calculations
- DIANA model has been validated for buckling at room temperature
- Next steps: considering a more realistic fire scenario (OZone, CFD) and considering the influence of the surrounding structure
- Read the full paper

https://www.abt.eu/actueel/publicaties-/besparen-met-fire-safety-engineering.aspx

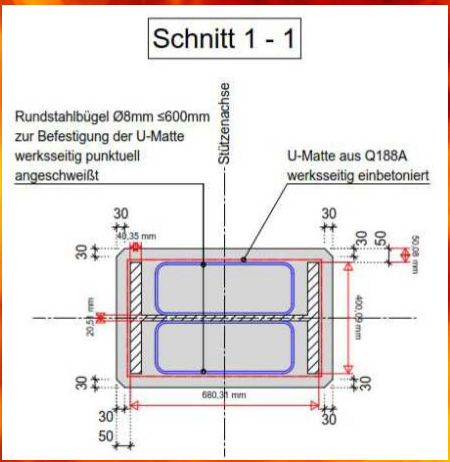
Tabel 2. Unity checks voor instabiliteit van de kolom bij brand, conventioneel vs FSE.

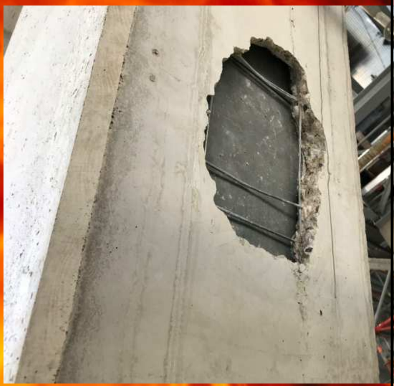
conventioneel standaardbrand	FSE natuurlijke brand	
uniforme staaltemperatuur eenvoudig berekeningsmodel (Excel)	uniforme staaltemperatuur eenvoudig berekeningsmodel (Excel)	temperatuurgradiënt geavanceerd berekeningsmodel (DIANA FEA)
10,4	1,07	0,92



Case II – Integrity of concrete protecting a steel column
Starting points

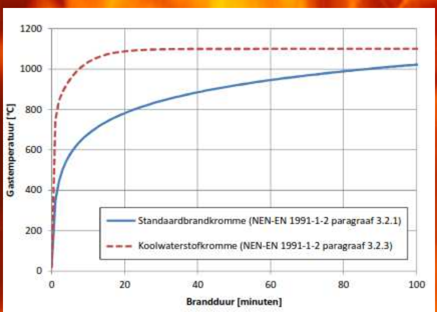
- 90 minutes of standard fire

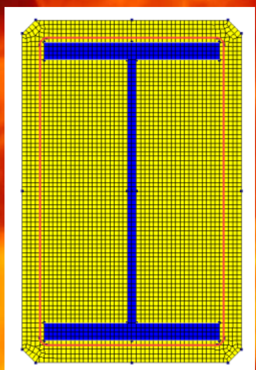




Case II – Integrity of concrete protecting a steel column
DIANA model

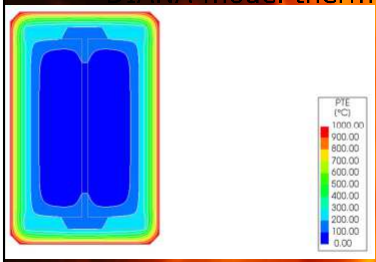
- Temperature-dependent mechanical and thermal properties according to NEN-EN 1992-1-2 (concrete and reinforcement) and NEN-EN 1993-1-2 (steel)
- Reinforcement assumed to be fully bonded (simplification)
- No-tension interface between steel and concrete

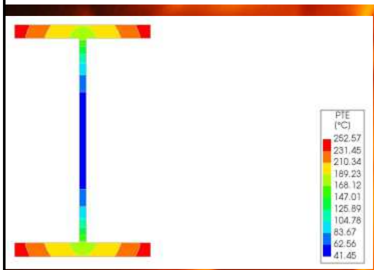


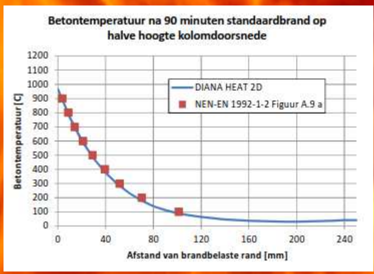


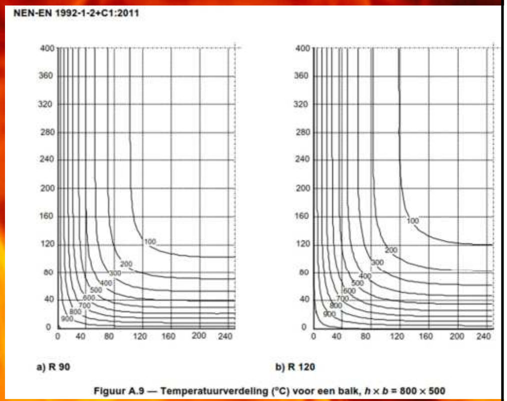
Case II – Integrity of concrete protecting a steel column

DIANA model thermal results



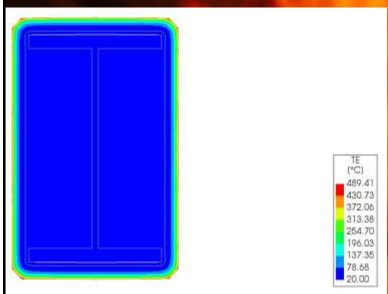


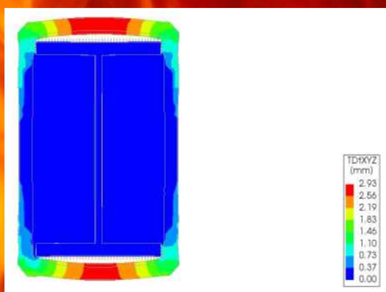


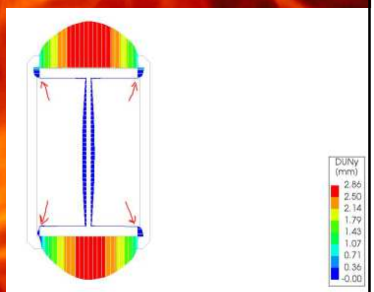


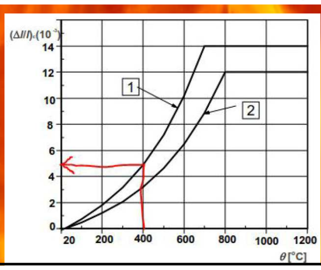
Case II – Integrity of concrete protecting a steel column

DIANA model thermo-mechanical results







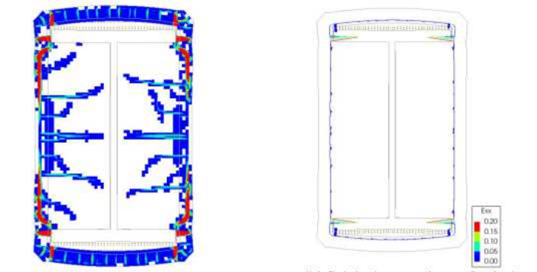


$$\kappa = \frac{\varepsilon}{h} = \frac{5 \cdot 10^{-3}}{50} = 10^{-4}$$

$$w_{\max} = \frac{1}{8} \cdot L^2 \cdot \kappa = \frac{1}{8} \cdot 480^2 \cdot 10^{-4} = 2.88 \text{ mm.}$$

Case II – Integrity of concrete protecting a steel column
Conclusions

- The concrete and reinforcement fail after about 10 minutes of standard fire
- The concrete between the flanges can still have a beneficial effect on the steel
- The minimum detailing requirements in NEN-EN 1994-1-2 (t >= 30 mm; Ø4-250; c = 20-50 mm) are not always satisfactory
- Considering a natural fire could have a more beneficial result



(a) Scheurvorming na 9 minuten brand (b) Rek in de wapening na 9 minuten brand

Questions?